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1 **TITLE:** A kinematic analysis of rugby lineout throwing

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37

38 Running Title: Lineout throwing technique

39

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ABSTRACT

To characterise rugby union lineout throwing technique, three experienced male rugby players performed throwing trials under varying conditions of distance and trajectory. Motion analysis permitted the recovery of joint centre coordinates at 120 Hz and the construction of a three-dimensional linked segment model for calculation of joint angle and centre of mass time histories. All participants exhibited greater accuracy at shorter throwing distances although the accuracy decrement was less in players of superior playing level. Participants demonstrated different technique alterations in order to perform throws of longer distances; either showing increased magnitudes of upper body joint angle velocities (less accurate thrower) or lower body joint velocities (more accurate thrower). The most elite thrower exhibited greater consistency in timing of peak joint angle velocities, with an overall standard deviation of 0.008 s compared with 0.027 s for the least accurate thrower. Data from participants of lesser ability suggest that changes are made to both magnitudes and timing of joint kinematics which leads to increased variability in performance. Implications for players / coaches include the need to develop core strength to permit limited changes to timing and magnitude of upper body joint actions whilst allowing sufficient end-point velocity to be imparted on the ball.

62

INTRODUCTION

63 The lineout in rugby union is the means of restarting play when the ball has
64 left the field of play. The lineout throw is executed by one player (normally the
65 'hooker') who throws the ball into the field of play towards units of jumpers /
66 lifters / support players who attempt to regain possession against fair
67 competition from the opposing team. A number of factors interact to determine
68 lineout success, including communication and timing between thrower and
69 jumpers, and the effectiveness of the opposition. However, one fundamental
70 requirement for a successful lineout is an accurate throw. The lineout throwing
71 action can therefore be considered an important individual skill within rugby
72 union.

73 The lineout is an important source of primary possession for a rugby team
74 which can often lead to scoring opportunities. At the elite level, the team in
75 possession retains possession in approximately 80% of their own throws and
76 in the last Rugby World Cup (2003) 26% of all tries were scored following
77 possession being gained from a lineout (International Rugby Board, 2003).

78 Basic lineout throwing technique will require many of the fundamental aspects
79 of throwing skills found in other sports, such as soccer throw-ins and
80 basketball shooting. However, lineout throwing technique is less regulated by
81 the laws of the game than its counterpart in soccer and this means that there
82 is obvious variation in technique between throwers at the same playing level.
83 For example, the throw is normally, but not always, executed with an overhead
84 action, the throw can be primarily 1-handed or semi or fully 2-handed, throwers

85 may maintain a stationary base during the throwing action (tandem or semi-
86 tandem) or indeed take a step forward with the ipsilateral or contralateral leg.
87 One feature of skilled lineout throwing is the ability to throw accurately under
88 conditions of varying distance (normally between 5-15 m horizontally) and
89 trajectory (e.g lob or flat). Changes to destination and trajectory are required
90 to maintain an element of surprise over the opposition and to provide an
91 advantage to the team with the throw. Different types of throw should be
92 executed with a similar technique, so that body actions do not portray too
93 much information to the opposition in terms of the intended throw location.
94 A limited amount of previous research has been conducted on lineout throwing
95 technique. McClymont (2002) provided a general description of lineout
96 throwing technique and emphasised some important biomechanical principles
97 for coaches / researchers to relate to lineout throwing. Sayers (2004)
98 performed one of the few quantitative technique analyses of lineout throwing
99 on a sample of elite players and emphasised the individual nature of throwing
100 technique and the increased involvement of the lower limbs in throws of longer
101 distance. However, there has been little detailed research on the technical
102 variations used by players of different standards to execute accurate throws
103 under varying conditions of both distance and trajectory. Such an analysis
104 would provide important information to coaches and players on technical
105 characteristics to focus on. Therefore, the purpose of this study was to provide
106 a kinematic description of successful lineout throwing and to identify technique
107 differences due to distance, types of throw and playing standard. It was

108 expected that more elite throwers would: demonstrate improved accuracy,
109 particularly at longer distances; exhibit more consistent movement patterns;
110 and exhibit more systematic technique changes when accommodating altered
111 task demands.

112

113 METHODS

114

115 *Participants*

116 Three experienced male rugby players participated in the study. Each
117 participant had a minimum of five years of lineout throwing experience in
118 training and competition settings. Participant A (age = 19 years, mass =
119 102.1 kg, height = 1.83 m) was Academy / University 1st XV level, Participant
120 B (age = 20 years, mass = 101.8 kg, height = 1.80 m) was an Under-21
121 International, and Participant C (age = 20 years, mass = 100.9 kg, height =
122 1.82 m) was a Senior International. All were free from injury and provided
123 written informed consent in accordance with the University Research Ethics
124 Committee procedures.

125

126 *Procedures*

127 After a self-directed warm-up including practice throws in an indoor
128 environment, participant body mass and height were recorded using standard
129 laboratory procedures. Subsequently, 39 spherical markers of 12.5 mm
130 diameter were attached to specific anatomical landmarks on the participant

131 for use with the Plug-In-Gait model. (Vicon™, Oxford Metrics Ltd., Oxford,
132 UK).

133 All participants then performed multiple throwing trials using their normal
134 technique and aiming for a static target located at the centre of a basketball
135 back-board. The participants threw from a constant position and the target
136 was moved to the appropriate distance for each trial. For all trials the target
137 was a height of 3.25 m from the ground, the approximate height reached by a
138 1.95 m tall player jumping with support to catch the ball. Each participant
139 completed 28 trials, with the order being randomised between participants.
140 The distribution was as follows: four 'flat' throws to 6 m; four 'lob' throws to
141 6 m; four 'flat' throws to 10 m; four 'lob' throws to 10 m; four 'flat' throws to
142 12 m; four 'lob' throws to 12 m; four 'flat' throws to 14 m. In all trials,
143 participants were asked to use their normal technique with the focus on
144 maximum accuracy. Suitable rest breaks were allowed to eliminate effects of
145 fatigue.

146

147 *Data Collection*

148 Kinematic data from each participant were recorded using an eight-camera
149 Vicon™ 612 motion analysis system (Oxford Metrics Ltd., Oxford, UK),
150 sampling at 120 Hz and calibrated to the manufacturer's instructions. A digital
151 video camera (Sony, DCR TRV-900E) operating at 50 Hz, and positioned
152 above and behind the thrower, captured video data to record the deviation of
153 the ball from the target (taped cross). The dimensions of the rectangular target

board were measured and used to produce four calibration points for use with the affine scaling technique. Two further 50 Hz digital video cameras (Sony, DCR TRV-900E) were placed in front of the participant at angles of approximately 45° to the intended direction of ball travel so that their optical axes intersected at an angle approximating 90°. Sequences from these two cameras were synchronised to within 1 ms by illuminating an array of 20 LEDs (sequentially at 1 ms intervals) in each camera view and used to reconstruct initial ball velocity and trajectory following ball release. The activity volume of the thrower and initial ball trajectory were calibrated using a 25-point 3-D calibration structure (Peak Technologies, Englewood, CO, USA) encompassing a 1.6 m x 2.2 m x 1.9 m volume.

Data Reduction

For each trial, 3D co-ordinates for each of the 39 reflective markers were reconstructed using Workstation software (version 4.5, Oxford Metrics Ltd., Oxford, UK). The marker trajectories were smoothed using a generalized cross-validatory spline (Woltring, 1986), and all subsequent data were processed using custom Matlab code (Matlab 7.0, Mathworks Inc., USA). A 14-segment kinematic model was then created from the calculated joint centre co-ordinates produced from the Plug-In-Gait model, consisting of head, trunk, upper-arm, forearm, hand, thigh, shank and foot segments. Segment inertia parameters (mass, centre of mass location and radius of gyration) were obtained from de Leva (1996) to calculate segment centre of mass (CM) time-

177 histories and subsequently determine the whole body CM trajectory. 3-D joint
178 angle trajectories were provided by the Workstation software from smoothed
179 marker trajectories. First time derivatives (velocities) of joint angles, segment
180 CM, and whole-body CM were obtained by fitting the position data with
181 interpolating quintic splines and outputting the derivative functions (Wood &
182 Jennings, 1979). The X-axis was perpendicular to the intended direction of
183 ball travel, with the positive direction to the right. The positive Y-axis pointed
184 in the intended direction of ball travel, and the Z-axis pointed vertically, with
185 the upwards direction being positive.

186 Resultant ball velocity was calculated by digitising (Peak Motus, version 8.1,
187 Englewood, CO, USA) the centre of the ball from recordings obtained by the
188 two synchronised video cameras with subsequent 3-D DLT reconstruction
189 (Abdel-Aziz and Karara, 1971). Final resultant velocity was reported as the
190 average of the five fields following ball release. To determine throw accuracy,
191 video images from the rear camera were digitised. An accuracy score was
192 produced by identifying the video field closest to which the ball made contact
193 with the target board and calculating the scaled displacement of the ball centre
194 from the target, with a score of zero indicating perfect accuracy. Ball release
195 was identified as the field of kinematic data following peak right hand velocity
196 (based on Fradet *et al.*, 2004).

197

198

RESULTS

199

200

Indicators of Performance

201 All participants were capable of producing very similar ball release
202 characteristics, in terms of release velocity and release angle (Figure 1). Ball
203 release velocity exhibited gradual increases as distance increased for all
204 participants. There was a general increase in release angle as distance
205 increased and also as expected differences between 'flat' and 'lob' throws to
206 the same distance.

207 Participant B and C demonstrated good accuracy (less than 0.4 m deviation
208 from target) and exhibited no trend towards decrements in throw accuracy
209 across throws of longer distance and different type (Figure 2). Participant A
210 did exhibit less accurate throws with increasing distance. With approximately
211 0.8 m mean deviation from the target the performance of participant A could
212 be considered unacceptable in the conditions 12 m-lob and 14 m-flat.

213

Throws of Different Distance - Whole body CM Variables

215 All participants generally developed an increased magnitude of vertical CM
216 (CMz) range of motion and peak velocity for throws to longer distance, with
217 the clearest trends for participant C followed by participant A (Figure 3a).
218 Participant B exhibited a much clearer trend for developing additional
219 horizontal CM (CMy) range of motion and velocity in the direction of the throw,
220 which was not as apparent for participant A or C (Figure 3b). Participant B
221 also used a technique which involved a step forward during the throwing
222 action. This meant that in addition to more marked increases above the

223 baseline (6 m-flat) than participant A or C, participant B actually started from
224 a higher baseline CMy peak velocity in the 6 m-flat condition than participant
225 C who used a stationary technique (at 6 m: participant B = $0.51 \text{ m}\cdot\text{s}^{-1}$,
226 participant C = $0.22 \text{ m}\cdot\text{s}^{-1}$; at 14 m: participant B = $0.80 \text{ m}\cdot\text{s}^{-1}$, participant C =
227 $0.26 \text{ m}\cdot\text{s}^{-1}$).

228

229 *Throws of Different Distance – Magnitude of Joint Angle Variables*

230 Additional velocity could also be developed through increases in the
231 magnitude of joint angle peak velocities at various links in the kinematic chain.
232 Participant C exhibited trends for increases in peak angular velocities in joints
233 more proximal in the chain (knee and hip) whereas participant A demonstrated
234 increases in peak velocities at all joints (Figure 4). Participant B did not exhibit
235 trends for increased joint angle peak velocities as distance increased.

236

237 *Throws of Different Distance – Timing of Joint Angle Variables*

238 The consistency of the timing (relative to time of ball release) in peak joint
239 angle velocities can provide an indication of the consistency in temporal
240 sequencing of the movement patterns (Table 1). Averaging the standard
241 deviation of the timing of peak joint angle velocities across all joints and all
242 distances shows that participant C showed minimal variability in the timing of
243 the joint actions within conditions (mean = 0.008 s) compared with more
244 variability demonstrated by participant B (mean = 0.020 s) and particularly
245 participant A (mean = 0.028 s).

246

247 *Throws of Different Types – Changes to Kinematic Variables*

248 The changes to technique made in performing 'lob' throws as opposed to 'flat'
249 trajectory throws were similar across all participants. These changes involved
250 an increased CMz range of motion (30-120%) and velocity (16-83%), brought
251 about primarily by gains in knee joint range of motion and peak velocity. To
252 ensure overall ball trajectory did not overshoot the target there was a curtailing
253 of shoulder joint range of motion and peak velocity. These changes were most
254 marked for the different types of throws at 6 m and gradually lessened as
255 throw distance increased and the permissible trajectory difference between
256 'lob' and 'flat' reduced (Figure 5).

257

258 DISCUSSION

259

260 The aim of this study was to provide a kinematic description of successful
261 lineout throwing and to identify technique variations between different
262 distances, types of throw and playing standard.

263

264 *Indicators of Throw Performance*

265 All participants were able to produce ball release characteristics (ball velocity
266 and release angle) sufficient to execute the task demands. Between-
267 participant accuracy differences (Figure 2) indicate that inter-individual
268 variations in skill level existed, and that participants B and C were the more

269 accurate, skilled lineout throwers. The accuracy differences between
270 participants would have practical importance, particularly at the longer
271 distances. Both participant B and C were able to maintain throw accuracy
272 within approximately 0.4 m for all throw distances and types. This is likely to
273 be an acceptable accuracy in practice whereby the jumper (intended recipient)
274 will have sufficient capacity to adjust for the catch within this radius. However,
275 participant A's deviation from the intended target approached a mean of 0.8 m
276 for the longer throw distances. Deviations of this amount would be difficult for
277 the jumper to adjust to and would also increase the likelihood of the opposition
278 jumpers being able to interrupt the ball's trajectory or for the throw to be
279 adjudged "not straight" by the referee, thereby relinquishing possession to the
280 opposition.

281

282 *Throws of Different Distance – Technique Changes*

283 It is evident that a number of basic throwing techniques can be employed in
284 order to execute successful lineout throwing. The laws of the game do not
285 constrain the technique used and so it is likely that a number of different
286 throwing "models" could be employed. Nevertheless, a number of basic
287 principles have arisen from the present study.

288 In players who use a stepping movement during the throwing action (e.g.
289 participant B) it seems possible to generate the additional momentum required
290 to throw to longer distances through the actual stepping movement with the
291 increase in whole body CM velocity this causes. Participant B did not exhibit

292 increased magnitudes of joint angle velocities at any link in the kinematic chain
293 and managed to maintain the timing of these joint actions within moderate
294 limits.

295 On the other hand, participant C maintained a stationary base of support
296 throughout the throwing action with a tandem (side-by-side) foot configuration.
297 This technique did not allow for increased ball velocity to arise from increased
298 whole body momentum in the direction of the throw. Rather, to throw for longer
299 distances the magnitude of joint angle velocities in the proximal joints of the
300 kinematic chain (the knee and hip) were increased above baseline. These
301 increased magnitudes were accompanied with extremely consistent timings
302 of the joint actions within a given throwing condition. Perhaps importantly,
303 there was little change in the peak magnitudes at the shoulder and elbow joint
304 in this participant throwing to longer distances. Combining the findings of
305 accuracy of this participant (and bearing in mind his international playing
306 level), the minimal change in upper body kinematics, and minimal variability in
307 any joint action timings would suggest that this throwing model fits into a
308 traditional perspective for aiming tasks, where consistent patterns are
309 maintained except for necessary changes in proximal segments away from
310 the end-point to generate the additional ball velocity. The findings of increased
311 involvement of the lower limb with minimal changes to upper body kinematics
312 concur with those of Sayers (2004).

313 Participant A utilised a throwing technique which began from a semi-tandem
314 position and finished in a tandem foot position via a small step taken during

315 the throwing action. Using this technique this participant had the opportunity
316 to increase CMy velocity through the stepping movement but to a lesser extent
317 than participant B. Results showed that participant A was also required to
318 increase the magnitude of peak joint angle velocities to produce the necessary
319 ball release characteristics, these changes occurring across all joints in the
320 kinematic chain. In this participant, these changes were accompanied by
321 increased variability of joint action timings across all throw distances and types
322 (compared with participant B and C) and a consequent decrement in throw
323 accuracy, particularly at longer distances.

324

325 *Throws of Different Type – Technique Changes*

326 Despite the differences in basic throwing action exhibited by the participants,
327 there appeared to be similar characteristic technique changes made in order
328 to alter the ball trajectory from 'flat' to 'lob' This essentially involved a transfer
329 to increased vertical body motion, primarily through an increase in knee range
330 of motion and peak knee angular velocity. The increased emphasis on
331 upwards motion led to increases in the ball's release angle between 'flat' and
332 'lob' of approximately 20° for the 6 m throws, reducing to approximately 10°
333 difference for the 12 m throws. To maintain the desired range to hit the target
334 this meant the ball release speed had to be reduced and this was done in all
335 participants by reducing the excursion and peak velocities developed at the
336 shoulder joint and additionally for participant C by a reduction in peak elbow
337 angular velocities.

338

339

Limitations

340 The number of participants sampled in this study is small, however it is evident
341 from this study and from Sayers (2004) that no “exemplar” lineout throwing
342 technique exists and so attempting any sort of group analysis would prove
343 problematic and likely lead to the masking of important between-player
344 technique differences. The present analysis has focussed on how given
345 individuals manage the altered task demands whilst highlighting how this can
346 differ between individuals. Nevertheless, it would be beneficial to repeat this
347 analysis on additional players from a range of playing standards and using a
348 range of throwing techniques to determine whether the observations accrued
349 from this study can be reinforced. The experimental trials occurred in a lab
350 environment, without the additional pressures of match play which may have
351 an influence on performance and perhaps on the technique used. It would be
352 possible to perform a kinematic analysis of lineout throwing in conditions more
353 similar to match situations (e.g. with live jumpers and opposition, as in Sayers
354 [2004]); however this makes obtaining a robust accuracy score difficult and so
355 this approach was avoided in the present study.

356

357

Practical Implications

358 A number of coaching implications arise from this study. Irrespective of the
359 basic throwing action (with step or stationary), in more successful throwers
360 there is little change made to the kinematics of the upper body (magnitude or

361 timing) when performing throws to longer distances. Therefore, any technique
362 used should encourage stable movement patterns in the upper extremity body
363 segments. Based on the current evidence it seems possible to execute
364 accurate throws to the long distances required in rugby union using a
365 technique with a stationary base (participant C). However, this requires
366 considerable increase in the magnitude of peak joint velocities of the lower
367 body and trunk and so it is speculated that this technique would require
368 players to have considerable strength in the lower limb and trunk muscles. For
369 players with more limited physical capacity successful performance can be
370 equally achieved by using a throwing action where the additional momentum
371 required is generated through a stepping motion with little increase in
372 magnitude of joint actions (participant B). The findings of participant A in this
373 study suggest that in players with a minimal stepping action and perhaps with
374 less “core” strength throws to longer distances require increased joint actions
375 at all links in the kinematic chain and this increases the chances of poor
376 coordination and degradation in accuracy. In this situation, it is recommended
377 that a transition to a stepping action would be beneficial.

378 In previous studies of lineout throwing technique, a focus has been put on the
379 deception required by the thrower to ensure the opposition do not “read” the
380 intended destination of the throw. This may be an important consideration
381 which has not been fully explored in this study design. However, it is evident
382 that consistent throwing techniques in terms of upper body kinematics perform
383 best in terms of accuracy and these should also be those techniques most

384 difficult to read. Moreover, in actual match situations it is likely that the
385 opposition will be able to decipher more valuable ball destination information
386 from the movements of the jumpers and support players in the line rather than
387 from the body actions of the thrower.

388

389 *Future Research*

390 In addition to analysing more players in a similar manner to improve the
391 generality of the presented results there are other interesting future directions
392 for this line of research. There is now an established body of literature
393 suggesting that movement variability is a feature of skilled performance (e.g.
394 Bartlett *et al.*, 2007), due to the need for adaptability of the system based on
395 environmental constraints and to correct for errors early in the movement
396 cycle. This issue has not been explored in the present study but would
397 certainly be of interest. It may be that the lineout throw is a sufficiently fixed /
398 closed skill that adaptability is not a major consideration, or it may be that more
399 in-depth analyses of the present data would highlight features of variability in
400 the skilled performances.

401

402 *Conclusion*

403 A number of different basic throwing techniques can be used for effective
404 lineout throwing to different distances and trajectories. Nevertheless, certain
405 basic principles appear necessary for successful performance; that is
406 consistent magnitude and timing of upper limb actions with additional

407 momentum for longer distances being generated only from increased
408 magnitudes of joint actions in the lower limb or a more pronounced stepping
409 movement. Attempting to increase throwing distance via changes to the
410 kinematics at all body joints in the system combined with inconsistent joint
411 action timings leads to inaccurate throws.
412

413

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444 smoothing. *Journal of Biomechanics*, 12, 477-479.

445

446 Table 1. Timing variability in peak joint angular velocities across multiple trials
 447 of 'flat' condition throws.

448

SD of Timing of Peak Joint Angular Velocity						
(s)						
Participant	Distance	Knee	Hip	Shoulder	Elbow	MEAN
A	6_flat	0.017	0.041	0.030	0.030	
	10_flat	0.022	0.031	0.018	0.036	
	12_flat	0.030	0.012	0.046	0.059	
	14_flat	0.014	0.012	0.022	0.007	0.027
B	6_flat	0.033	0.031	0.004	0.004	
	10_flat	0.091	0.008	0.004	0.008	
	12_flat	0.022	0.012	0.012	0.008	
	14_flat	0.035	0.020	0.008	0.004	0.020
C	6_flat	0.005	0.008	0.005	0.005	
	10_flat	0.011	0.008	0.011	0.005	
	12_flat	0.012	0.006	0.004	0.006	
	14_flat	0.005	0.004	0.019	0.008	0.008

449

450 List of Figures

451

452 Figure 1. (a) Ball release velocity across all throwing conditions; (b) Ball
453 release angle across all throwing conditions.

454

455 Figure 2. Mean throw accuracy across throwing conditions.

456

457 Figure 3. (a) Percentage change (from 6 m_flat condition) in peak CM vertical
458 velocity for all flat throwing conditions; (b) Percentage change (from 6 m_flat
459 condition) in peak CM horizontal velocity for all flat throwing conditions.

460

461 Figure 4. Percentage change (from 6 m_flat condition) in peak joint angular
462 velocities for: a) knee; b) hip; c) shoulder; d) elbow.

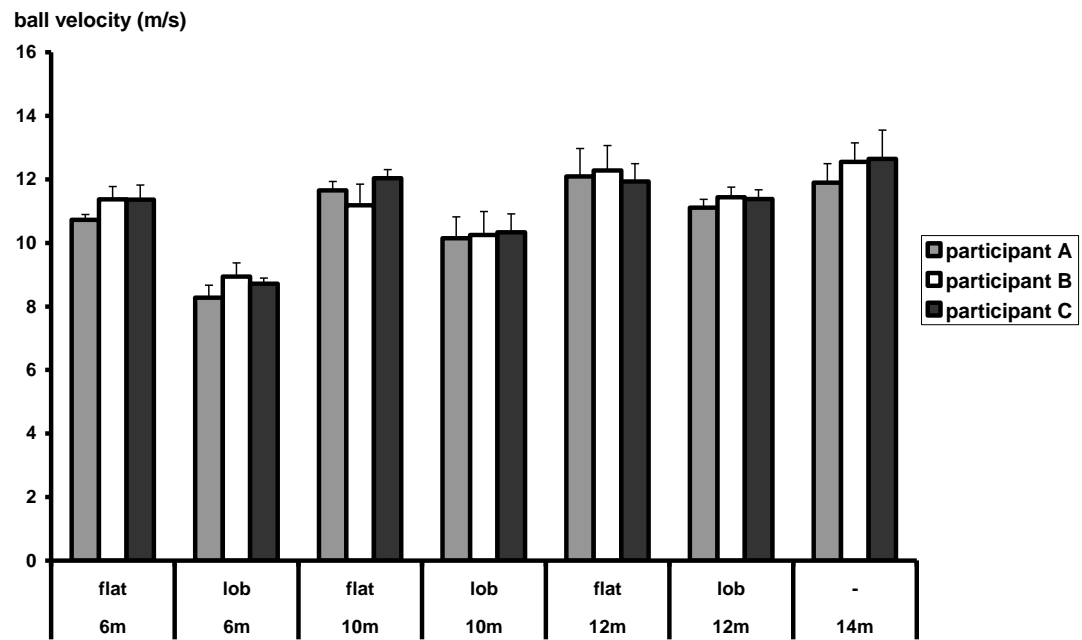
463

464 Figure 5. Percentage change (from equivalent 'flat' condition) for analysed
465 body CM and joint angle kinematic variables for: a) participant A; b) participant
466 B; c) participant C.

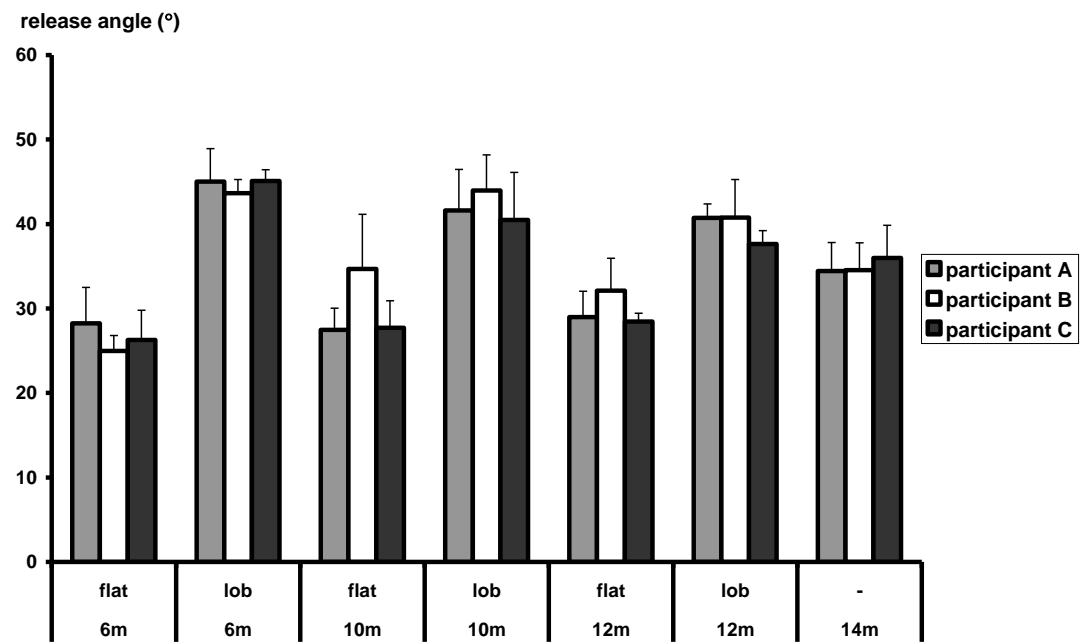
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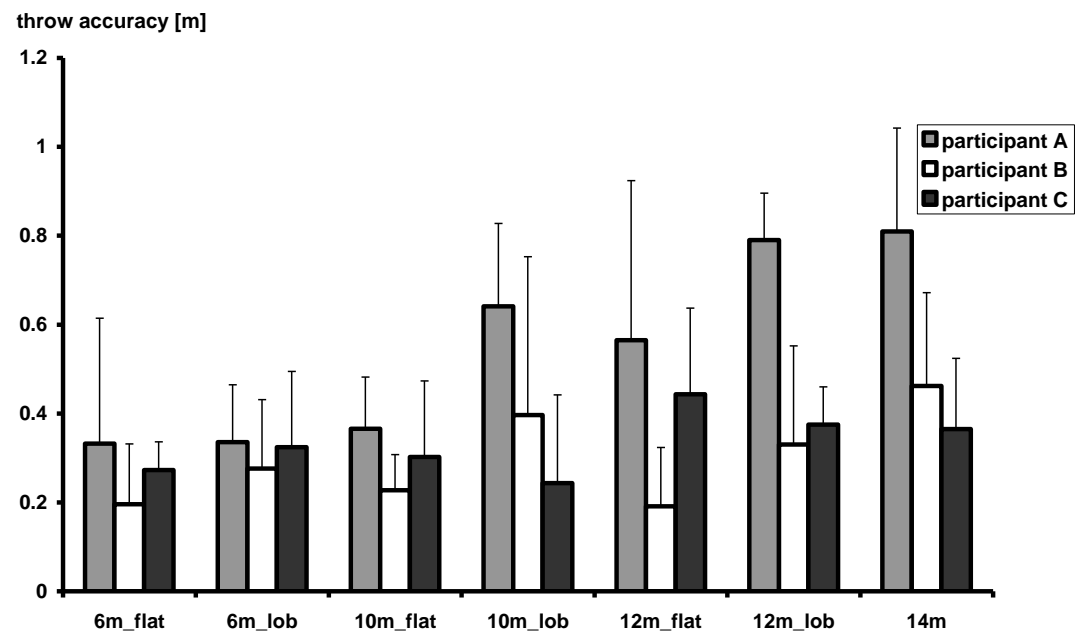
(a)



(b)



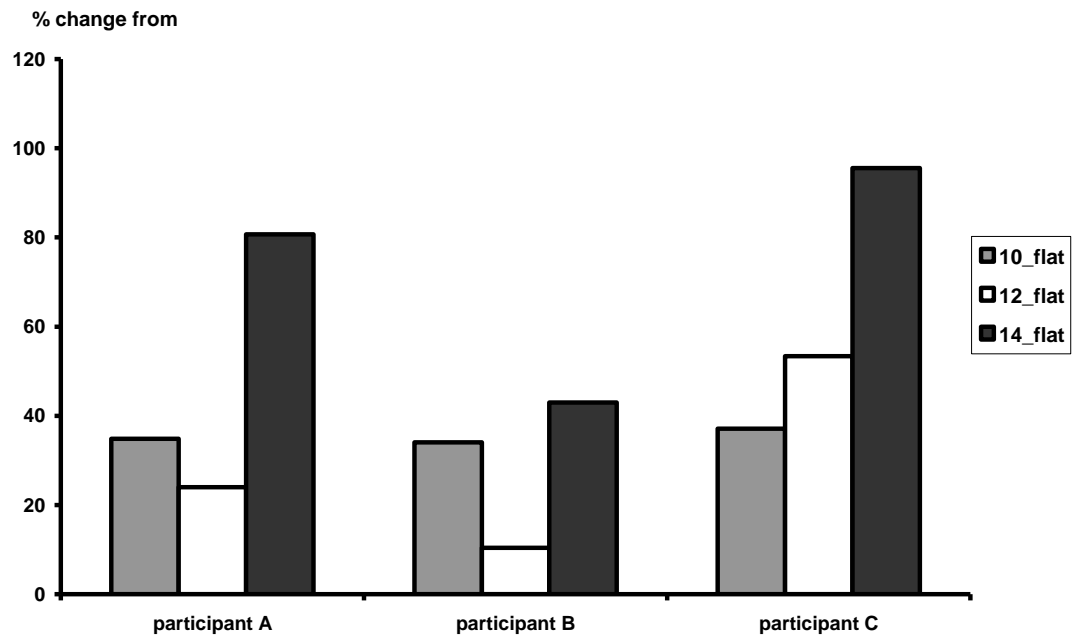
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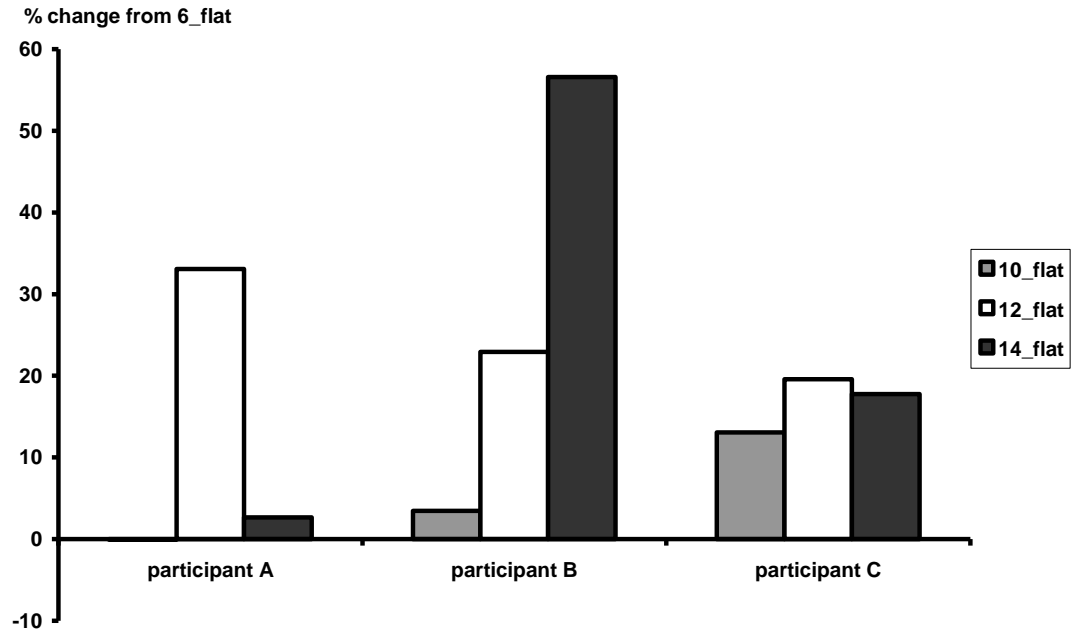
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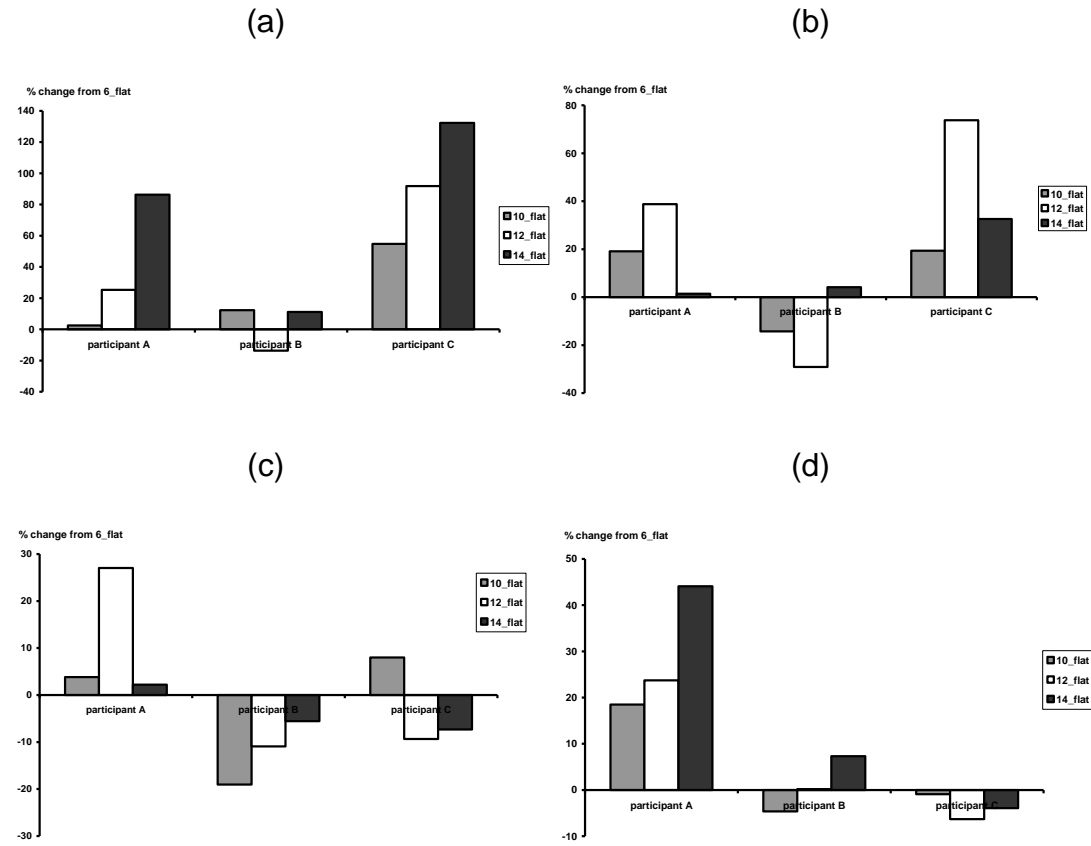
472 Figure 2

(a)

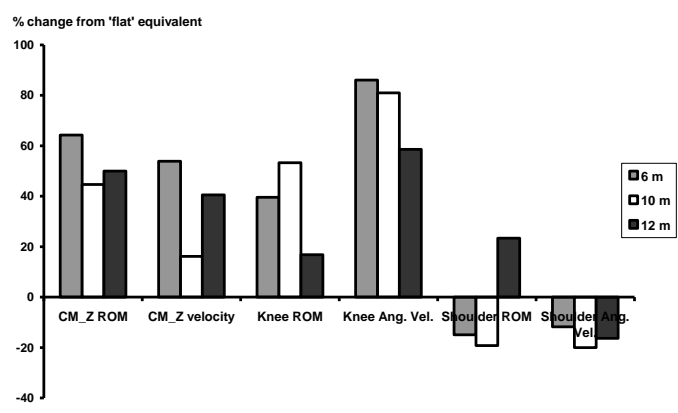


(b)

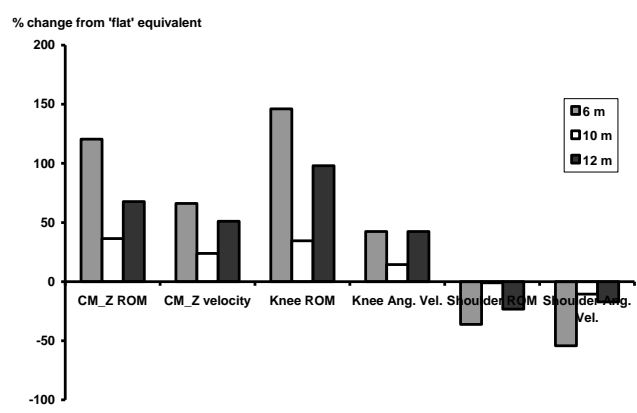




(a)



(b)



(c)

